Recycling of Plastic Films through Solvent Targeted Recovery and Precipitation

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STRAP

Plastics Production and Impacts

It is often said that we live in the plastics age. Plastics are consumed across all sectors (clothing, medicine, construction, food packaging, etc.) as plastics are versatile, low cost, and easy to manufacture (Singh et al., 2017). However, the final disposal of plastics is a global concern. If plastics leak into the environment, some microplastic could break away from larger plastic products, and move through air and water systems, finding their way into the food chain and posing risks to biodiversity, food availability, and human health (Li et al., 2016). One of the main priorities of governments and cities across the globe is to address these issues by reducing the production of virgin plastics and limiting the generation of waste plastics through recycling. The current plastic recycling industry is primarily based on mechanical recycling of rigid and clean materials that are easier to process such as beverage bottles (made from polyethylene terephthalate, PET), and milk jugs (made from high density polyethylene, HDPE). Most plastic materials, however, are contaminated with other plastics, dyes/inks, fillers, and other materials. Mechanical recycling often does not produce high quality plastics from these contaminated materials, which is the case for most flexible packaging containers (Al-Salem et al., 2009). Flexible plastics, like plastic bags, account for over 35 % of the plastics produced in 2015 (UNEP, 2018) and are the most used material for packaging globally (Figure 1). Unfortunately, flexible plastic materials usually end up in open dumps, landfills, or are incinerated after use since they cannot be easily mechanically recycled, resulting in a series of cascading environmental impacts. Figure 1 shows the breakdown of packaging by material type detailing the demand of rigid and flexible plastic packaging.

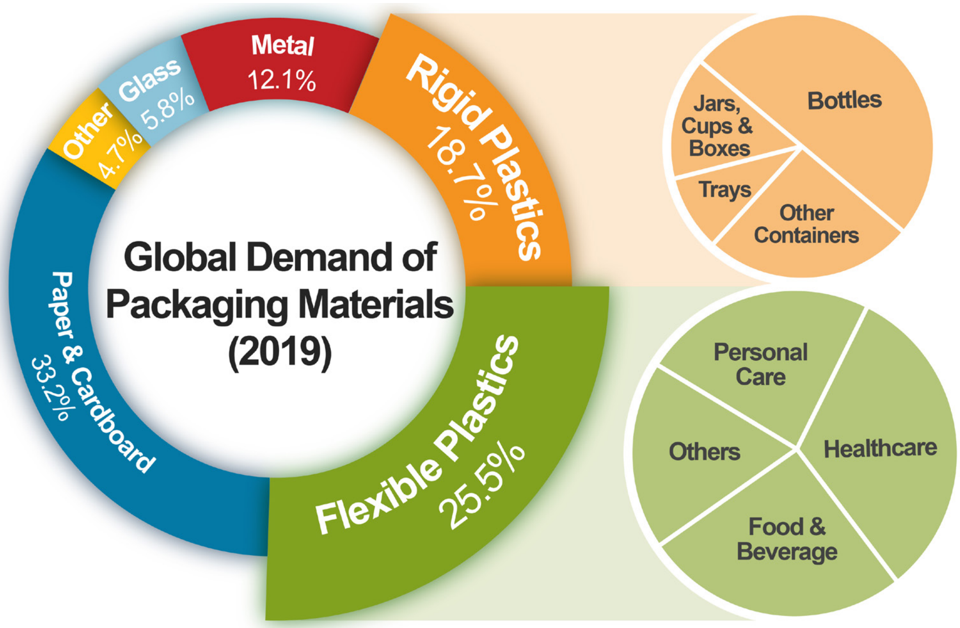

Figure 1. Global demand of packaging materials in 2019 (adjusted from Statista, (2022)) detailing the demand of rigid plastic packaging (for 2017 based on Ceresana, (2019)) and flexible plastic packaging (for 2017 based on Grand View Research, (2018)).

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Plastic packaging materials, in the form of multilayer films, are mixtures of several and different plastic layers which are combined to achieve specific properties that cannot be provided by single plastic layers. Combining different layers of plastics results in stronger and impermeable materials with unique properties that help preserve food quality and lifetime (Figure 2). The multilayer packaging materials allow less material to be used which reduces greenhouse gas emissions. These multilayer plastics can also help reduce food waste through smaller portion packaging that can be consumed more efficiently. The properties of these multilayer films cannot be achieved with one single plastic material. The advantages of multilayer films are numerous, but multilayer plastics cannot be mechanically recycled easily because the different layers are chemically incompatible. One promising technology to effectively recover these layers is known as solvent-targeted recovery and precipitation (STRAP), which breaks down multilayer films into their original plastic building blocks (Walker et al., 2020).

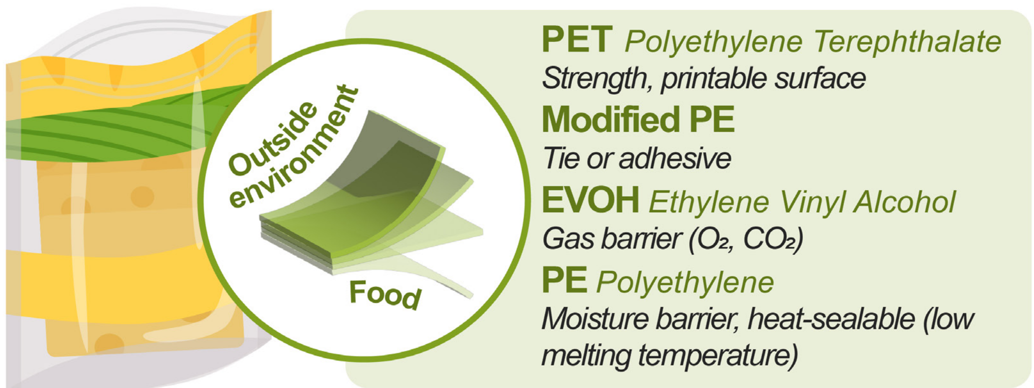

Figure 2. Graphical representation of the different layers of multilayer films and properties/attributes of each material.

Recycling Plastic Films through STRAP

Technology Basics

Multilayer films are among the most challenging plastic wastes to recycle, but the STRAP technology can recover the individual plastic components in multilayer plastic materials. In general terms, STRAP "washes" multilayered films several times with solvents to separate the multiple components mixed in plastic films into single components, known as resins (Figure 3). These resins can then be reused to make more of the product from which they originated, or they can be used to manufacture products with higher value or quality (known as upcycling). There are different multilayer materials that can be processed with STRAP including clear rigid multilayer films used in food containers, printed multilayer films used for

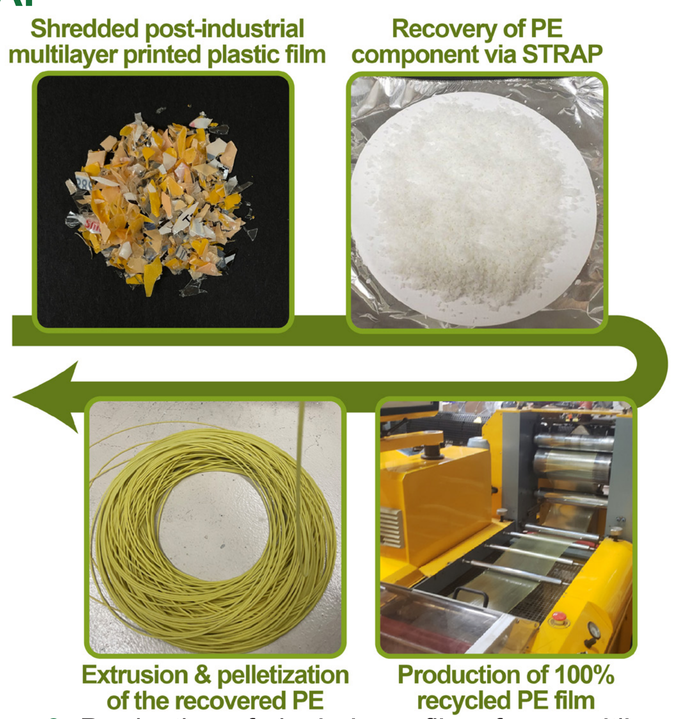

Figure 3. Production of single layer films from multilayer films through STRAP.

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food packaging, mixed multilayer plastic waste, disposable face masks, and other plastic waste collected along with municipal solid waste (MSW). For more information on the technical details of the STRAP process, the reader can refer to (Walker et al., 2020).

Showing the Scalability of STRAP

The current limitation of STRAP is that our process only produces small quantities of final material, less than 0.11 kilograms (0.25 pounds) per week. To make this technology commercially viable, larger quantities of materials that plastics converters require in production need to be manufactured. To demonstrate the STRAP technology at a larger scale, a process development unit (PDU) was designed and tested to produce 25 kilograms (55 pounds) per hour of recycled resins from waste flexible and rigid plastics. Figure 4 shows a simplified STRAP diagram featuring the recovery of high purity plastic resins from mixed plastic waste or flexible plastics.

The first step in the STRAP process is to shred the as-received mixed plastic waste into smaller size particles that are uniform and small/light enough to move continuously and steadily (or flow) in the reactor tanks. After shredding, the smaller plastic particles are fed into a specially designed dissolution tank. A solvent selectively dissolves a targeted plastic from the mixture. The dissolved plastic (liquid/slurry form) and non-dissolved plastic (solid form) are separated using filtration. The non-dissolved plastic is transferred to a solvent recovery system while the dissolved plastic is pumped into a precipitator. In the precipitator, the solvent is cooled and the plastic precipitates; that is, it turns into a solid. The plastic is then sent to a solvent recovery system for a second time. The solvent is completely recovered and re-used in the process. The recovered plastic is then extruded into pellets and sold to plastic convertors. The amount of solvent in the pellet is controlled during the drying and extrusion processes.

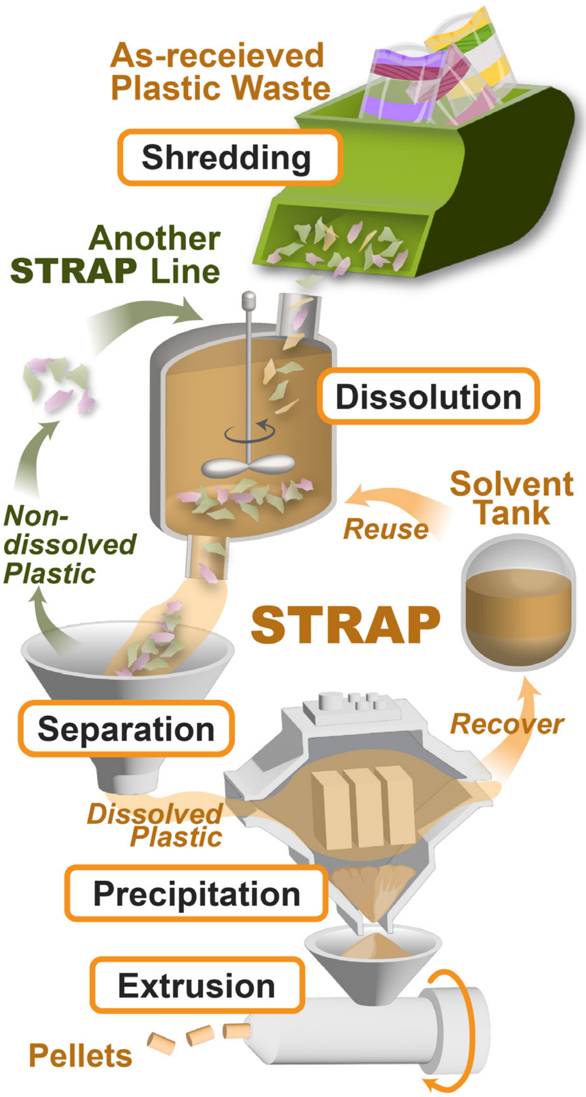

Figure 3. Simplified STRAP process flow diagram.

Economics and Environmental Benefits of STRAP

The STRAP process can produce high quality resins at costs comparable to the virgin resins, according to detailed process models based on our experimental data. The STRAP process has 60 to 70 percent lower greenhouse gas (GHG) emissions than producing the virgin polymer. Figure 4 shows the emissions to recover polyethylene via STRAP from a multilayer food

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packaging film vs emissions of virgin packaging made from petroleum. All energy (electricity, steam, natural gas, etc.) and material (e.g., water, solvents, other chemicals) inputs were evaluated from extraction of raw materials to production of polyethylene at the plant for both polyethylene products (STRAP vs petroleum). Figure 4 shows that the total GHGs of extracting polyethylene via the STRAP process (0.7 kilograms of carbon dioxide equivalents per kilogram of polyethylene) are 68% lower than the impacts of producing polyethylene from fossil sources (2.2 kilograms of carbon dioxide equivalents per kilogram of polyethylene).

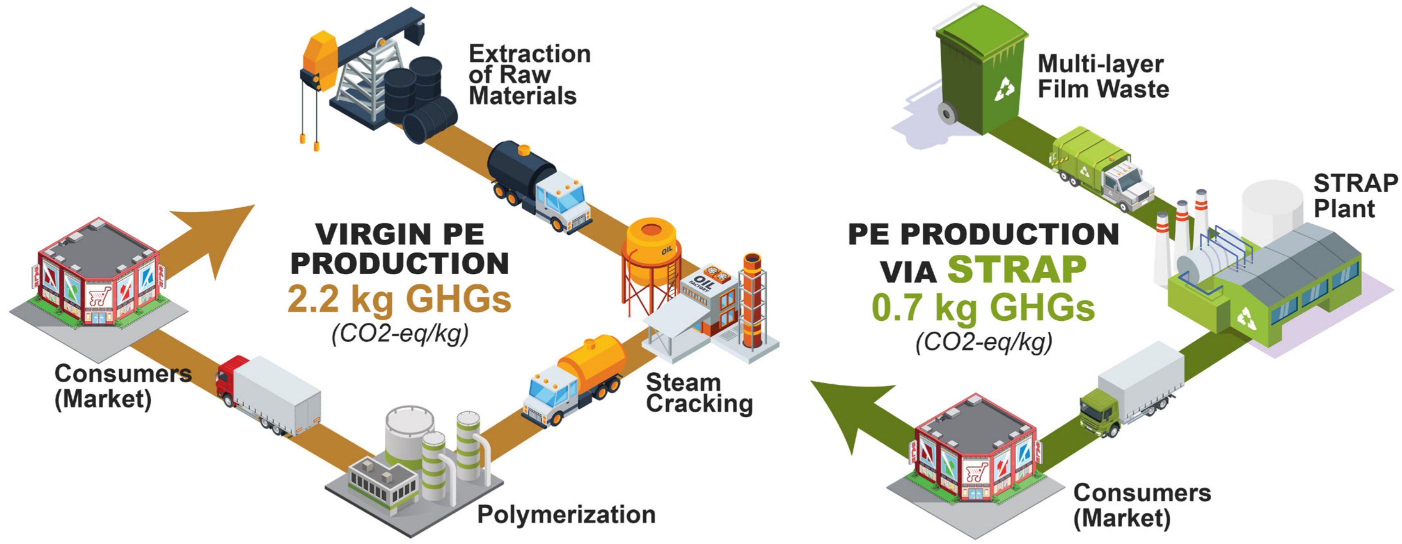

Figure 5. Climate change impacts from the STRAP process and the production of polyethylene (PE) from fossil fuels.

There are several other environmental benefits from STRAP. These include eliminating undesirable end-of-life scenarios like disposal of mixed plastic waste in landfills, incineration, creation of micro and nano plastic contaminants, and pollution of oceans.

Initiatives to Install the First STRAP Commercial Plant

The Green Bay and Northeastern Wisconsin area is a major hub for flexible packaging, label production, printing, and associated plastics industries and constitutes a natural location to develop the first STRAP commercial plant . Wisconsin ranks 8th in the nation in terms of plastics industry employment with over 43,000 people working in this sector and a direct plastic's payroll of US$2.3 billion. This leadership is even higher (3rd in the nation) for flexible packaging products with over 25,000 people currently employed with projected 9% growth in the next 10 years (Plastics Industry Association, 2023). For example, Amcor, one of the largest packaging companies in the world, has 17 facilities in Wisconsin. Many companies in the food industry use plastic products, which generate billions of dollars annually. In addition, there are numerous local, national, and international manufacturing companies in Northeastern Wisconsin that make equipment to support the plastic and flexible packaging industries. As a leader in both production and consumption of flexible packaging products, Wisconsin has an enormous potential to host the first STRAP commercial plant, maximizing the efficiency in terms of material availability and transport of waste plastic multilayer films and recovered resins. Moreover, the University of Wisconsin-Madison and the University of Wisconsin-Stout have well established programs in plastics and packaging and are currently doing outstanding research in plastics and STRAP.

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Summary

Plastic waste generation has been increasing over the years, as the recycling rate for plastics is low compared to other materials. Moreover, conventional mechanical recycling methods are not technically or economically feasible for many multilayered plastic films, which are the main materials used for food packaging. The solvent-targeted recovery and precipitation (STRAP) technology breaks down the mixed plastic waste and recovers high-quality pure plastic resins. STRAP can process various types of plastic wastes including printed multilayer films used for food packaging, mixed multilayer plastic waste, disposable face masks, and other plastic waste collected along with municipal solid waste. A process development unit is being built to demonstrate this technology at a larger scale.

- The STRAP process can economically recover polyethylene from multi-layer film waste at scale.
- The environmental analysis shows that the recovery of polyethylene via the STRAP process generates fewer greenhouse gas emissions than the production of virgin polyethylene from petroleum.

References

- Ceresana. (2019, March). Rigid Plastic Packaging Market Report – World. https://ceresana.com/en/produkt/rigid-plastic-packaging-market-report-world
- Grand View Research. (2018). Flexible Plastic Packaging Market Size, Share & Trends Analysis Report By Material (Polyethylene, Polyamine, PVC), By Type (Flat Pouches, Stand-Up Pouches), By Application, And Segment Forecasts, 2018 - 2025. https://www.grandviewresearch.com/industry-analysis/flexible-plastic-packaging-market
- Li, W. C., Tse, H. F., & Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. Science of the Total Environment, 566–567, 333–349. https://doi.org/10.1016/j.scitotenv.2016.05.084
- Plastics Industry Association. (2023). Facts and Figures of Wisconsin. https://www.plasticsindustry.org/factsheet/wi01
- Singh, N., Hui, D., Singh, R., Ahuja, I. P. S., Feo, L., & Fraternali, F. (2017). Recycling of plastic solid waste: A state of art review and future applications. Composites Part B: Engineering, 115, 409–422. https://doi.org/10.1016/j.compositesb.2016.09.013
- Statista. (2022, March 10). Distribution of packaging demand worldwide in 2019, by material type. https://www.statista.com/statistics/271601/packaging-materials-in-the-global-packaging-market-since-2003/
- United Nations Environment Programme (UNEP). (2018). Single-Use Plastics: A Roadmap for Sustainability. https://wedocs.unep.org/handle/20.500.11822/25496
- Walker, T. W., Frelka, N., Shen, Z., Chew, A. K., Banick, J., Grey, S., Kim, M. S., Dumesic, J. A., van Lehn, R. C., & Huber, G. W. (2020). Recycling of multilayer plastic packaging materials by solvent-targeted recovery and precipitation. Science Advances, 6(47). https://doi.org/10.1126/SCIADV.ABA7599/SUPPL_FILE/ABA7599_SM.PDF

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